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Rapid Communication

First records of the mourning gecko (*Lepidodactylus lugubris* Duméril and Bibron, 1836), common house gecko (*Hemidactylus frenatus* in Duméril, 1836), and Tokay gecko (*Gekko gecko* Linnaeus, 1758) on Curaçao, Dutch Antilles, and remarks on their Caribbean distributions

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Abstract

Globally, geckos (Gekkonidae) are one of the most successful reptile families for exotic species. With the exception of the widespread invader, *Hemidactylus mabouia*, however, introductions of exotic gecko species are a more recent occurrence in the Caribbean islands despite extensive introductions of exotic geckos in the surrounding Caribbean region. Here we report three new exotic gecko species establishments on the mid-sized Caribbean island of Curaçao (Leeward Antilles). Of the three new exotic species, the mourning gecko, *Lepidodactylus lugubris* (Duméril and Bibron, 1836) has the largest distribution on Curaçao and has likely been established for the longest time. The common house gecko, *Hemidactylus frenatus* (in Duméril, 1836) has a limited distribution and was likely a more recent introduction. Finally, the Tokay gecko, *Gekko gecko* (Linnaeus, 1758), escaped from captivity and is known from a single locality. Both *L. lugubris* and *H. frenatus* have had widespread distributions in the greater Caribbean region for over 70 years yet have only been reported from Caribbean islands within the past decade. Comparatively, the scope of *G. gecko* introductions on Caribbean islands is similar to *L. lugubris* and *H. frenatus* but introduced populations of *G. gecko* in the greater Caribbean region are virtually absent. These patterns indicate that different introduction pathways (intentional vs passive) may affect the size of exotic geographic ranges, and that the rate of exotic gecko introductions to Caribbean islands may now be increasing.

Key words: invasion, Lesser Antilles, lizard, neotropics, non-native, parthenogenic species, Sauria

Introduction

Geckos are one of the most prolific exotic (non-native) reptile groups with six gecko species in the top 20 exotic herpetofaunal species globally (Bomford et al. 2009). Given this global success, surprisingly, only the

gecko, *Hemidactylus mabouia* (Moreau De Jonnès, 1818), has a widespread distribution across the Caribbean Islands despite climatic suitability in the region for many gecko species. Endemic to Africa, *H. mabouia* likely established in the Caribbean during the slave trade or earlier (Kluge 1969; Powell and Henderson 2012), and has since spread to more than 100 Caribbean islands (Powell and Henderson 2012).

Comparatively, two other globally successful geckos, *Hemidactylus frenatus* (in Duméril, 1836) and *Lepidodactylus lugubris* (Duméril and Bibron, 1836), both native to the Indo-Pacific, have been spread to Pacific islands outside of their native ranges since World War II or earlier (Hunsacker II and Breese 1967; Case et al. 1994) yet are only reported to have established on Caribbean islands within the past two decades (Powell and Henderson 2012; Borroto-Paez et al. 2015; Alonso Bosch and Borroto Páez 2017; Lorgelec et al. 2017). These geckos are considered “weedy” human commensal species (Carranza and Arnold 2006) that are easily transported inadvertently as stowaways via cargo shipping (Powell et al. 2011; Powell and Henderson 2012).

In contrast to the accidental transport of “weedy” human commensal gecko species, other larger gecko species, like the Tokay gecko, *Gekko gecko* (Linnaeus, 1758), are often introduced to new locations intentionally. These charismatic species are common as pets and can escape from captivity or are intentionally released to aid in pest control or simply enhance the local ambiance (King and Krakauer 1966; Wilson and Porras 1983; Henderson et al. 1993). Although not as widespread globally as *L. lugubris* and *H. frenatus*, the southeastern Asian native, *G. gecko*, has several established populations outside of its native range (Henderson et al. 1993), yet are also rare across Caribbean islands.

For the most part, Caribbean islands have fewer exotic gecko species relative to localities in other regions, however, this pattern may be shifting. Here we provide the first reports of three exotic gecko species, *Lepidodactylus lugubris*, *Hemidactylus frenatus*, and *Gekko gecko*, established on Curaçao, a mid-sized (444 km²) island in the southern Caribbean ca. 70 km north of Venezuela. Although *H. mabouia* has been established on Curaçao since the late 1980s (van Buurt 2011), it appears that these three new exotics have established more recently, likely within the past decade. In addition, we summarize the spread of these three exotic species across the Caribbean islands and the larger Caribbean region.

Materials and methods

On Curaçao, exotic geckos were sighted, and when possible captured by hand and/or photographed. For most captured individuals, sex was recorded, SVL was measured, and a non-lethal tissue sample (tail tip or buccal swab) was taken for DNA analyses. Individuals were then released

Table 1. *Lepidodactylus lugubris*, *Hemidactylus frenatus*, and *Gekko gecko* found. Note that some coordinates are not provided to maintain privacy of homeowners; and although *L. lugubris* are presumed to be all female, only gravid individuals (G) are noted as female.

Location Found	Coordinates	Date	Sample ID	SVL (mm)	Sex	Genbank number
<i>Lepidodactylus lugubris</i>						
Private residence	Jan Sofat	16 Aug 2009	NA	NA	Unknown	NA
Private residence	Willemstad	19 Sept 2016	HEMA-CU01	NR	Juvenile	MG049677
		24 Sept 2016	HEMA-CU11	45	Unknown	NA
		24 Sept 2016	HEMA-CU12	43	Female – G	NA
Lion's Dive Resort	12.0871N; –68.8978W	23 Sept 2016	HEMA-CU08	30	Juvenile	MG049679
		23 Sept 2016	HEMA-CU10	20	Juvenile	MG049680
Rancho El Sobrino Resort	12.3632N; –69.1547W	25 Sept 2016	HEMA-CU18	32	Juvenile	MG049682
		25 Sept 2016	HEMA-CU20	21	Juvenile	NA
Santa Barbara Resort	12.0676N; –68.8515W	27 Sept 2016	HEMA-CU27	40	Female – G	NA
		27 Sept 2016	HEMA-CU28	39	Unknown	NA
<i>Hemidactylus frenatus</i>						
Zoo	12.1300N; –68.8944W	13 Feb 2017	HEMA-UR29	55	Male	MG049673
		13 Feb 2017	LELU-UR05	53	Female	MH541093
		13 Feb 2017	LELU-UR06	43	Juvenile	NA
Private Residence	Willemstad	4 March 2017	HEMA-UR68	47	Male	MG049674
		4 March 2017	HEMA-UR69	52	Female – G	MH541094
Renaissance Curaçao Resort and Casino	12.1059N; –68.9403W	11 March 2017	HEMA-GU57	40	Male	MH541095
		11 March 2017	HEMA-GU58	53	Female	MH541096
		11 March 2017	HEMA-GU59	55	Female – G	MH541097
<i>Gekko gecko</i>						
Private residence	Santa Catharina	8 April 2018	NA	NA	Unknown	NA

at the site of capture. All samples were assigned an identification code unique to this study (Table 1). *Lepidodactylus lugubris* and *Hemidactylus frenatus* were found during night time surveys conducted between 19:30 and 23:00 h; *Gekko gecko* was found by local residents and reported to GVB.

To confirm the identity of *Lepidodactylus lugubris* and *Hemidactylus frenatus*, we sequenced a 725–1202 bp region of the mitochondrial cytochrome *b* gene from our tissue samples. Total genomic DNA was extracted using either a standard phenol-chloroform protocol, the Qiagen DNeasy Blood and Tissue Kit (Qiagen, Valencia, CA), or Chelex extraction protocol (Estoup et al. 1996). Amplification was accomplished using either primers cytbS1L:F (5'-GAAAAACCGCYRTTGTWWTTCAACTA-3') and cytbH15:R (5'-ACTGGTTGDCCYCCRATYCAKGTKAG-3') or rGlu-1L:F (5'-GAAAAACCRCCGTTGTWATTCAACTA-3') and rPro-1H3:R (5'-TWA AAATKCTAGTTTGGG-3'). For samples using the second primer pair, rGlu-1L and an internal primer, cytb2F-2 (5'-ACAACGCCACCCTA ACACGATT-3') were used for sequencing. DNA sequencing was performed by Genewiz (South Plainfield, NJ), and resultant sequences were compared to the GenBank nucleotide database using BLAST.

We did not conduct genetic analyses to confirm identification of *Gekko gecko*; it has a unique and easily recognizable phenotype, and we were provided the single introduction pathway source for the introduced individuals on Curaçao.

Finally, we searched the literature and compiled a time series of introductions of *Lepidodactylus lugubris*, *Hemidactylus frenatus*, and *Gekko gecko* to Caribbean islands and the greater Caribbean region to elucidate patterns of spread. We define the Caribbean islands following Smith et al. (2005) as the islands of the Greater Antilles, Lesser Antilles, Lucayan Archipelago (The Bahamas) and southern Dutch Antilles islands (Aruba, Bonaire, and Curaçao). We define the greater Caribbean region as locations within a relatively close shipping distance to the Caribbean islands, namely southern United States and Mexico, Central America, and northern South America. Note, these records indicate introductions that may or may not have resulted in successfully established populations that currently persist.

Results

Lepidodactylus lugubris

On 16 August 2009, we first observed and photographed *Lepidodactylus lugubris* in Curaçao at a private residence in Jan Sofat (Figure 1A), however, it was initially misidentified as the native gecko, *Thecadactylus rapicauda* (Houttuyn, 1782) until we examined the photograph more closely. From 19–27 September 2016, we found nine *L. lugubris* at four locations across Curaçao (Table 1). Initially, several of these individuals were identified as *Hemidactylus mabouia*, however, DNA analyses on four of the individuals confirmed they were *L. lugubris*. The remaining five individuals were positively identified as *L. lugubris* based on phenotypic characters. Because body coloration can change for both *H. mabouia* and *L. lugubris*, especially with the stress of being handled, the following characters were easiest to use to distinguish the two species in the field: *L. lugubris* has small, granular, smooth dorsal scales whereas *H. mabouia* has noticeable dorsal tubercles, and *L. lugubris* has a wide neck that tapers very little, occasionally with endolymphatic chalk sacs (Figure 1B), whereas *H. mabouia*'s neck tapers and is narrow (Figure 1C).

At a private residence, we found a juvenile *Lepidodactylus lugubris* missing its tail (HEMA-CU01) on an outdoor wall, and two adults in an indoor bathroom. The larger (45 mm SVL) adult (HEMA-CU11) had well-developed endolymphatic chalk sacs on its neck (Figure 1B) and the smaller (43 mm SVL) adult (HEMA-CU12) was gravid. We surveyed the Lion's Dive Resort, whence several other exotic species have reportedly originated on Curaçao (M. Boot, *pers. comm.*), and found two juvenile *L. lugubris* on outdoor walls near lights (HEMA-CU08, CU10). At the Rancho El Sobrino Resort at the northern end of Curaçao, we found two juvenile *L. lugubris* (HEMA-CU18, CU20) near outdoor lights. Finally, at the Santa Barbara Resort at the southern end of Curaçao, we found two adult *L. lugubris* near outdoor lights (HEMA-CU27, CU28; Figure 1C).



Figure 1. A. *L. lugubris* from a private residence in Jan Sofat in 2009 (photo: G. van Buurt); B. Dorsal and ventral views of *L. lugubris* (HEMA-CU11) with well-developed endolymphatic chalk sacs (neck) (photo: M.R. Helmus); C. *L. lugubris* (left; HEMA-CU28) and *H. mabouia* (right) side-by-side (photo: M.R. Helmus); D. *H. frenatus* (HEMA-UR29) with dark dorsal pattern (photo: M.R. Helmus); E. *H. frenatus* (HEMA-GU57) with light dorsal pattern (photo: T.J. Tran); F. *G. gecko* on an outdoor wall with tape measure for scale (photo: Savine Boersma); G., H. *G. gecko* captured at private residence in Santa Catharina (photo: S. Boersma). Photograph locality information is in Table 1.

The larger individual (CU27) was gravid and both had well-developed endolymphatic chalk sacs. Based on body coloration, all *L. lugubris* appear to be clone A (Zug 2013).

Hoogmoed and Avila-Pires (2015) compiled a comprehensive distribution map of *Lepidodactylus lugubris* in the New World, which was later expanded by Señaris et al. (2017). We further expanded the distribution to include our records on Curaçao, plus recent introductions to Cuba (Alonso Bosch and Borroto Páez 2017), The Bahamas (Krysko and MacKenzie-Krysko 2016) and Grand Cayman (Goetz and Burton 2018). Although *L. lugubris* was reported in Colón, Panama in 1916 (Fugler 1966),

shortly after the Panama Canal opened in 1914, the earliest introduction to a Caribbean island is estimated to be nearly a century later in 2008 in Cuba which has resulted in an established population (Alonso Bosch and Borroto Páez 2017) (Figure 2, Supplementary material Table S1). Including Curaçao, *L. lugubris* has now been introduced to five Caribbean Islands.

Hemidactylus frenatus

From 13 February–11 March 2017, we found eight *Hemidactylus frenatus* at three locations. Although they were phenotypically similar to *H. mabouia* and *Lepidodactylus lugubris*, they were identified as an unknown species in the field, and our DNA analyses confirmed they were *H. frenatus* (Table 1). We first encountered three adult *H. frenatus* (HEMA-UR29, LELU-UR05, UR06; Figure 1B) on a metal fence in an overgrown garden area behind the Curaçao Zoo. We then found two adult *H. frenatus* (HEMA-UR68, UR69) on an outdoor wall behind a framed piece of art at a private residence in close proximity to the Curaçao Zoo. Finally, we found three adult *H. frenatus* (HEMA-GU57, GU58, GU59; Figure 1C) on a concrete outdoor wall at the Renaissance Curaçao Resort and Casino, adjacent to Curaçao's cruise ship terminal. The *H. frenatus* we found were consistently in the dark away from lighted areas, and we found a gravid individual at all three locations.

To our knowledge, no map of the Caribbean region comparable to the one compiled by Hoogmoed and Avila-Pires (2015) for *Lepidodactylus lugubris* exists for the other two exotic gecko species we found on Curaçao. Therefore, we compiled similar maps using records from the literature. The earliest record of *Hemidactylus frenatus* in the Caribbean region is from Sinaloa, Mexico in 1938 (Hardy and McDiarmid 1969) (Figure 2, Table S1). It was later reported on the islands of Cozumel, Mexico in 1980 (Lee 1996) and Key West in 1993 (Meshaka et al. 1994; Krysko et al. 2016). Its earliest record for a Caribbean island is 2008 in both the Dominican Republic (Powell and Henderson 2012) and Guantánamo, Cuba (Powell et al. 2011). Including Curaçao, there are now reported introductions to three Caribbean islands.

Gekko gecko

The L'Aldea restaurant in Santa Catharina offers a 90-minute cultural and ecological Mesoamerican experience for visitors, which includes seeing 130 species of live animals, one of which is *Gekko gecko*, a species not native to Mesoamerica. The curators procured *G. gecko* in 2011, kept them in a wire mesh enclosure, and did not account for the fact that i) *G. gecko* adults would mate and ii) resulting juveniles would be small enough to pass through the mesh. As a result, *G. gecko* juveniles indeed escaped from the exhibit, matured, and have established a breeding population in the neighborhood

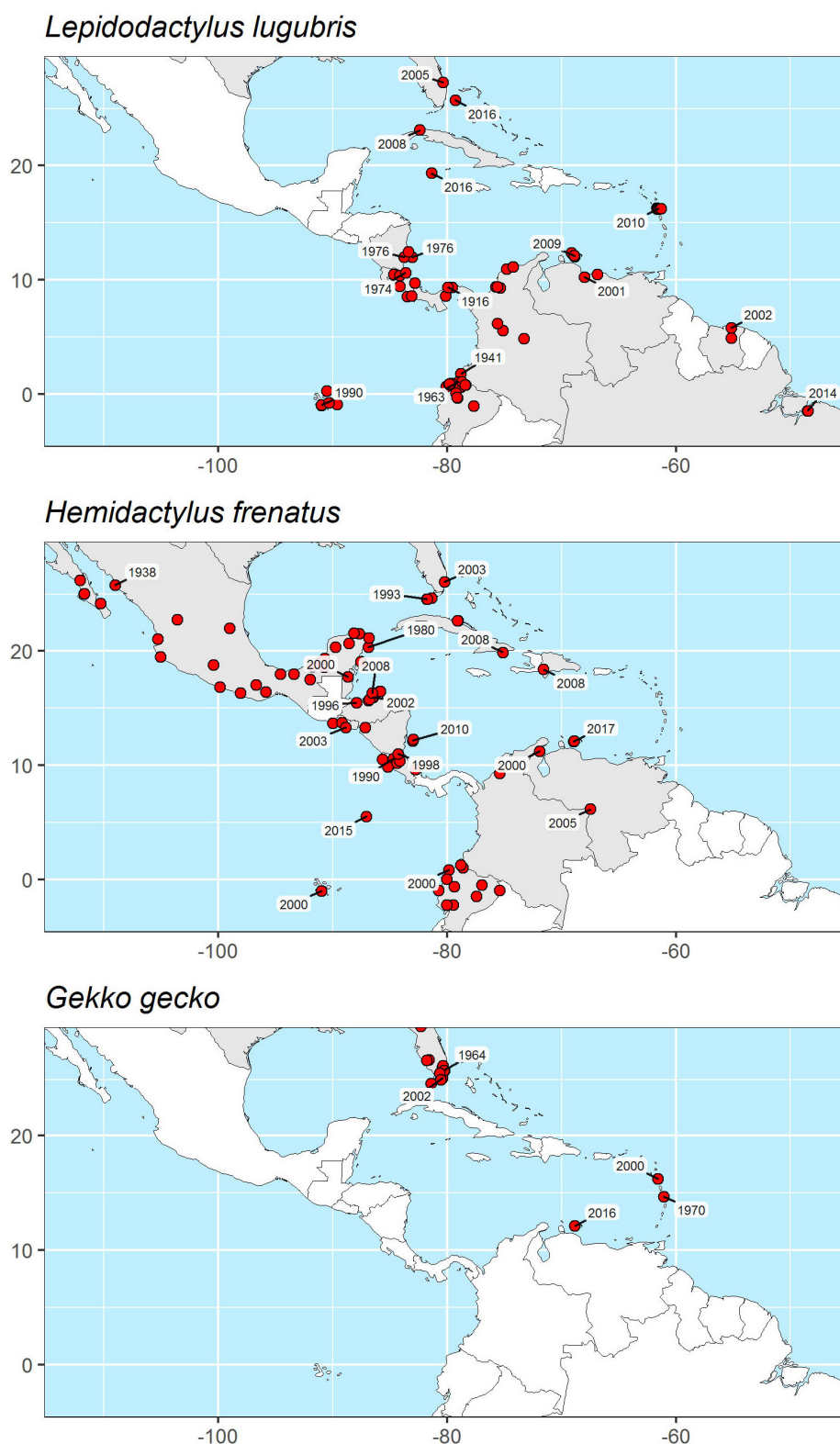


Figure 2. Distribution of *Lepidodactylus lugubris*, *Hemidactylus frenatus* and *Gekko gecko* in the Caribbean region. Points indicate location of documented introduction; years indicate earliest year documented in a country or island; shading indicates the species has been introduced to that country. For details see Table S1.

of Santa Catharina. The established population was brought to our attention on 8 April 2018 (Figure 1E–G), however, anecdotal reports from residents suggest that *G. gecko* has been established there prior to 2016.

Compared to *Lepidodactylus lugubris* and *Hemidactylus frenatus*, *Gekko gecko* has a much smaller distribution in the Caribbean region, only present in Florida and three Caribbean islands (Figure 2, Table S1). It was first reported regionally in 1964 in Miami, having been released from a pet dealer (King and Krakauer 1966). Its earliest Caribbean island record is from the 1970s in Martinique where it was released by an employee of a rum distillery who had brought individuals back from a trip to southeastern Asia (Henderson et al. 1993). Introductions of *G. gecko* to Florida, Curaçao, and Martinique were all intentional, while the circumstances of the introduction of *G. gecko* to Guadeloupe were not reported (Breuil et al. 2009; Lorvelec et al. 2011).

Discussion

All three exotic gecko species, *Lepidodactylus lugubris*, *Hemidactylus frenatus*, and *Gekko gecko*, have established reproducing populations on Curaçao. *Lepidodactylus lugubris* has the widest distribution on Curaçao and our records suggest that it has likely been there the longest. It seems to prefer edificarian habitats (buildings), as all individuals we found were on buildings, although further studies are needed to determine its full habitat preferences. Comparatively, *H. frenatus* appears to have a narrower distribution, and our records suggest a more recent introduction. Although we found *H. frenatus* in developed areas, it was not always near lights or on buildings, indicating it may more easily spread into the natural habitats of Curaçao. The presence of endolymphatic chalk sacs in *L. lugubris*, which are used by females for synthesizing egg shells (Ineich and Gardner 1989; Bauer 1989), as well as visible eggs in the abdomens of both *L. lugubris* and *H. frenatus* indicates both species are reproducing in multiple locations. Finally, *G. gecko* is restricted to a single locality near the captive population and likely is the most recent establishment. Together, there are now four exotic geckos established on Curaçao and although they potentially affect the native ecosystems on Curaçao, including the three native gecko species, these impacts have not been assessed.

While the invasion route for *Gekko gecko* is clear, we surmise that the other two exotics were likely introduced accidentally through cargo, such as animal feed, and/or landscaping and building materials. *Hemidactylus frenatus* could have been introduced to the Curaçao Zoo directly through a shipment of animal feed from Venezuela (H. Isena, *pers. comm.*) or from a company located near the Zoo which receives animal feed shipments from Florida as both localities have established populations of *H. frenatus* (Krysko et al. 2005; Fuenmayor et al. 2005). Alternatively, or additionally, it may have been introduced to the port in Curaçao in a shipment from any of the surrounding locations that also have *H. frenatus* (Figure 2). In the case of *Lepidodactylus lugubris*, it may have been introduced to one of the

resorts, and then transported to other locations through landscaping materials. Other studies have used genetic data to demonstrate that exotic lizard populations comprise introductions from multiple locations (e.g., Kolbe et al. 2004). Based on our genetic sequence data, this does not seem to be the case for *L. lugubris* or *H. frenatus* as all individuals of the species possessed a single haplotype and therefore were genetically identical to each other for the large section of cytochrome *b* we sequenced.

All three exotic species have been introduced to a similar number of Caribbean islands, however their distributions are still dwarfed by that of *Hemidactylus mabouia*'s across 100 plus islands. It is possible that *Lepidodactylus lugubris* and *H. frenatus* are legitimately absent on other Caribbean islands, or that their phenotypic similarity to *H. mabouia* has made them more difficult to positively identify (Alonso Bosch and Borroto Páez 2017). Closer examination of preserved specimens, photographs, and/or more intensive surveys may be necessary to determine whether these species are more widespread than currently reported.

Both *Lepidodactylus lugubris* and *Hemidactylus frenatus* were established in the surrounding Caribbean region for at least 70 years before being reported on a Caribbean island. This lag in introductions may reflect historically distinct shipping networks for the mainland Caribbean versus the Caribbean islands that have recently become more integrated. It is also noteworthy that both *L. lugubris* and *H. frenatus* which are likely transported to new locations accidentally, have much wider distributions in the region than *G. gecko* which is largely transported intentionally. With the continued increase in shipping traffic, Caribbean islands are likely to receive more exotic introductions in the near future (Helmus and Behm 2018). In conclusion, it appears that the spread of exotic geckos in the Caribbean is increasing; the extent of their spread and their impacts on native ecosystems certainly need further study.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Year and locality of *G. gecko*, *H. frenatus* and *L. lugubris* introductions in the Caribbean region.

Appendix 1. List of references for Table S1.

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